

# **FIRST Observations of Downwelling Infrared Radiation from 200 to 800 cm<sup>-1</sup>**

## **Table Mountain California and Cerro Toco Chile**

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CLARREO SDT Meeting

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# Background

- In late 2011, FIRST won a small ESTO intramural competition
- Funding used to calibrate FIRST using the SDL LWIRCS blackbody which had recently been calibrated at NIST LBIR
- FIRST calibrated in "ground based" and "space view" mode
  - *Two publications in Applied Optics, Latvakoski et al., 2013, 2014*
- FIRST deployed to Table Mountain Aug-Oct 2012
- FIRST also deployed to Cerro Toco, Chile Aug-Oct 2009
- Updates reported today:
  - Completion of analysis of dry day at Table Mountain
  - Radiosonde data from Cerro Toco became available in May 2014
  - First look at analysis of Cerro Toco data – 10 times less H<sub>2</sub>O than TMF

# FIRST Calibration Results

## Absolute Calibration, 1-sigma values

<u>Scene Temp (K)</u>	<u>Ground Based</u>	<u>Balloon/Space</u>
310.35	0.2 K	0.17 K
270.55	0.3 K	0.15 K
247.42	1.0 K	0.23 K
225.18	1.5 K	0.30 K
209.41	2.6 K	0.32 K
189.33	3.5 K	0.54 K
169.05	4.5 K	-----

*FIRST calibration measured across range  
of geophysical scene temperatures*

*Results reported in Latvakoski et al., 2013; 2014, Applied Optics*

# On-Site at Table Mountain and Cerro Toco



**Table Mountain, California**  
**7500 Feet**  
 $p = 775 \text{ hPa}$   
**September – October 2012**

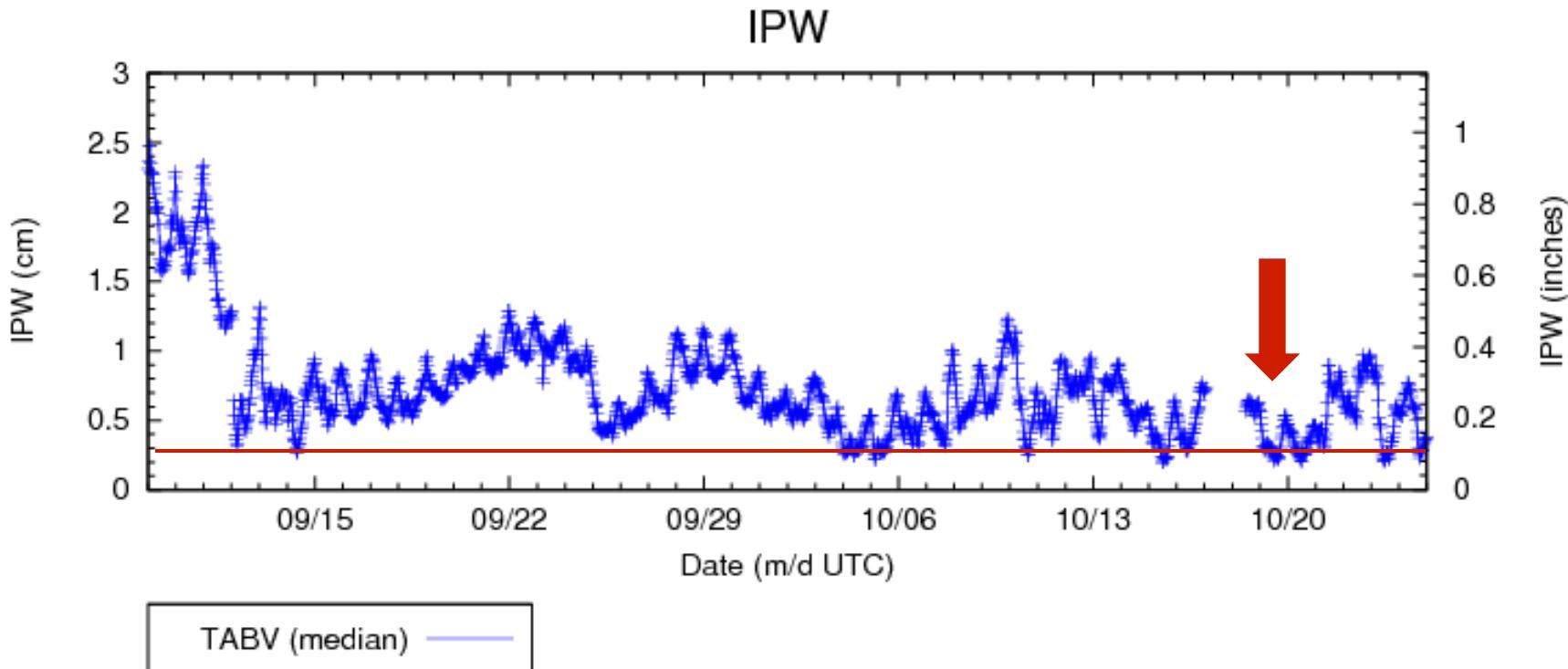


**Cerro Toco, Atacama Desert, Chile**  
**17,500 feet**  
 $p = 550 \text{ hPa}$   
**August – October 2009**

# Current Status

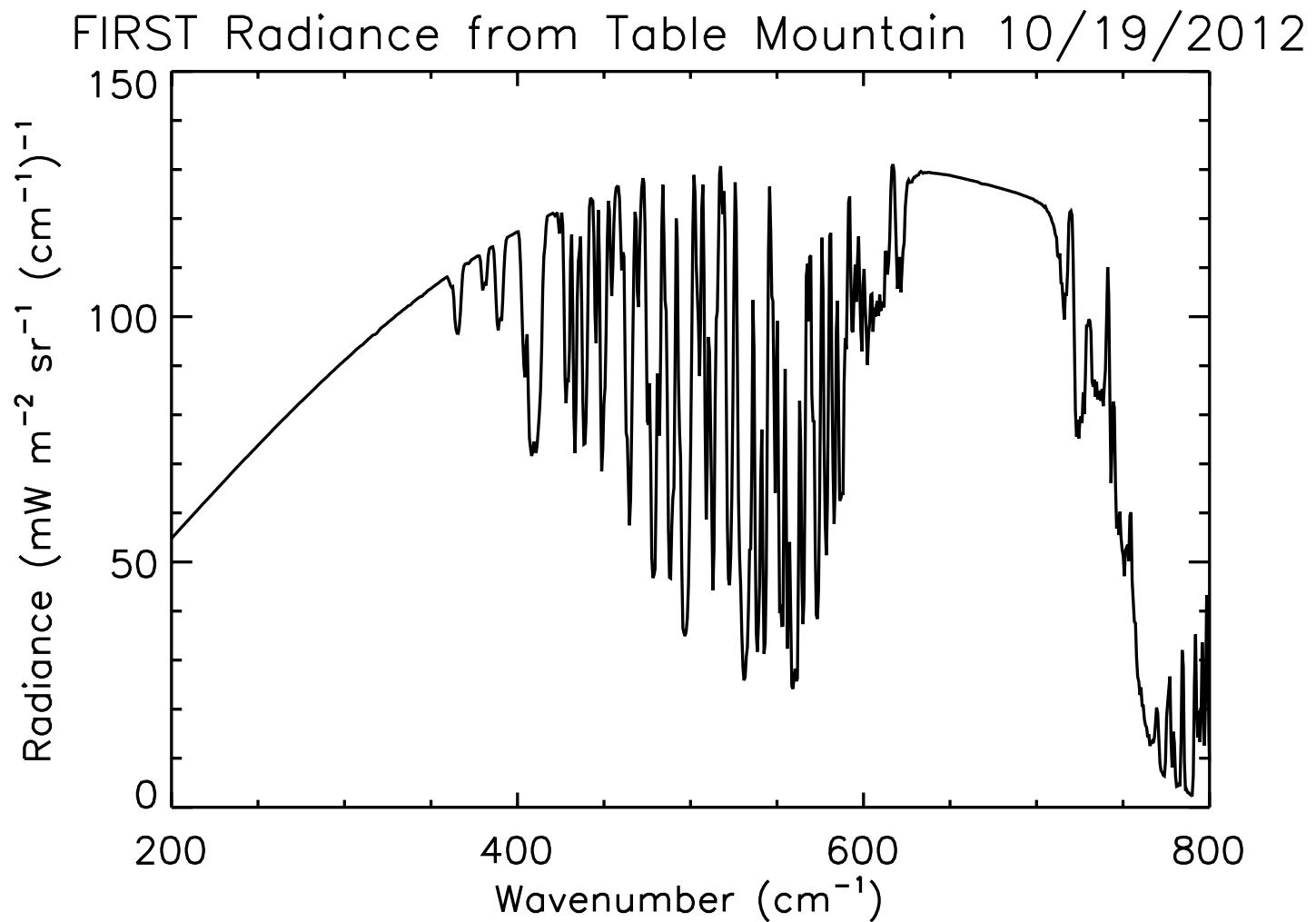
- Forward modeling
  - Using LBLRTM – substantial improvement in comparing FIRST far-IR radiances with computed radiances – due to LBLRTM H<sub>2</sub>O line parameters
- Calibration
  - Bolometer non-linearity correction
    - Harri Latvakoski reported on at the January 2014 SDT
- Results/ Status
  - Both updated FIRST datasets (TMF, Cerro Toco) available for study
  - At TMF, comprehensive assessment of model and measurement uncertainty completed – reporting these today
  - FIRST observations on driest day (0.28 cm IPW) at TMF agree with modeling to within combined uncertainty
  - Initial analysis of Cerro Toco looking very good

# GPS-Met Time Series of Precipitable Water at Table Mountain 9/2012 – 10/2012

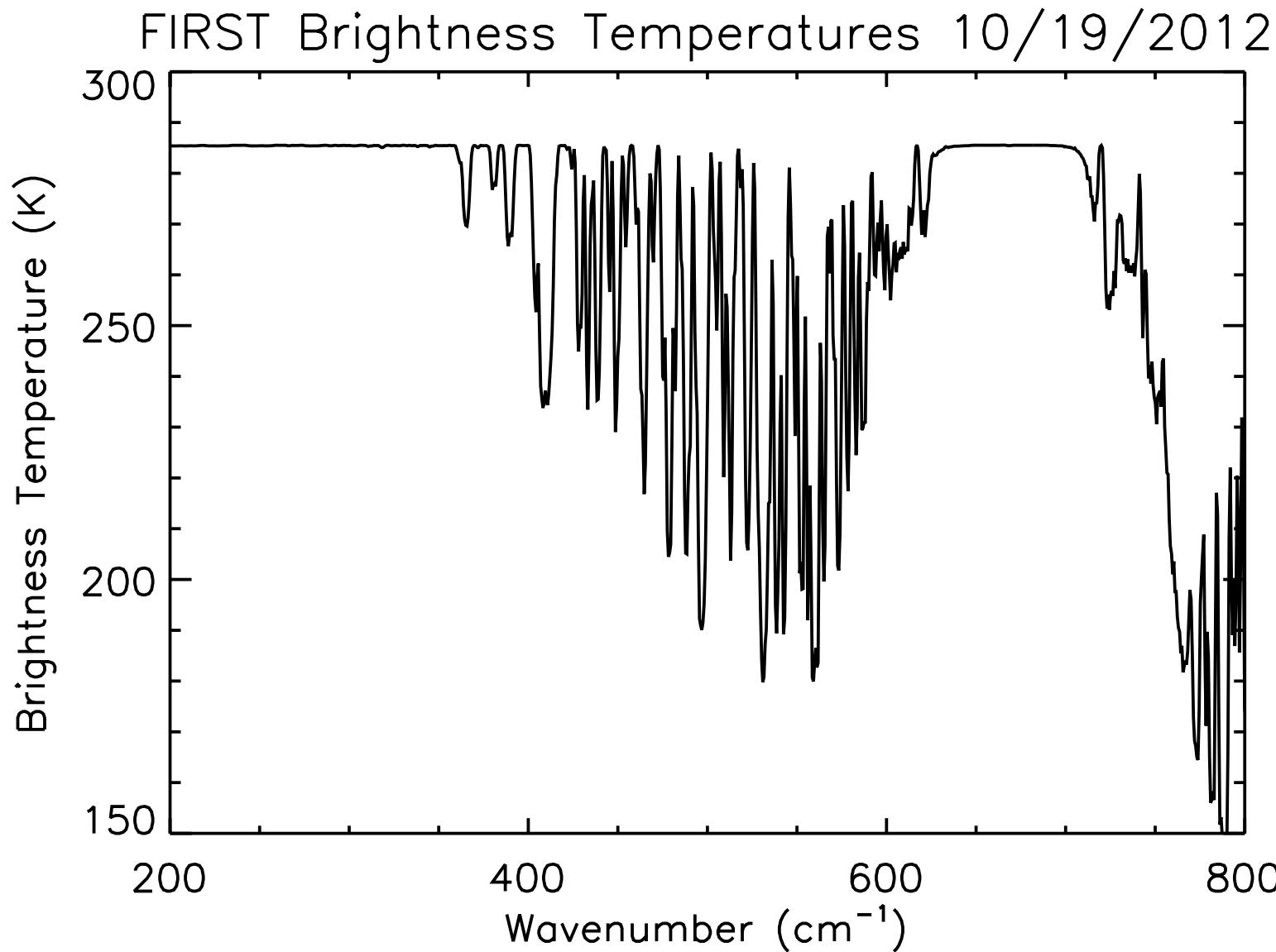


Driest day was 10/19, approximately 0.3 cm (or 3 mm) of IPW

# FIRST Downwelling Radiance Spectrum



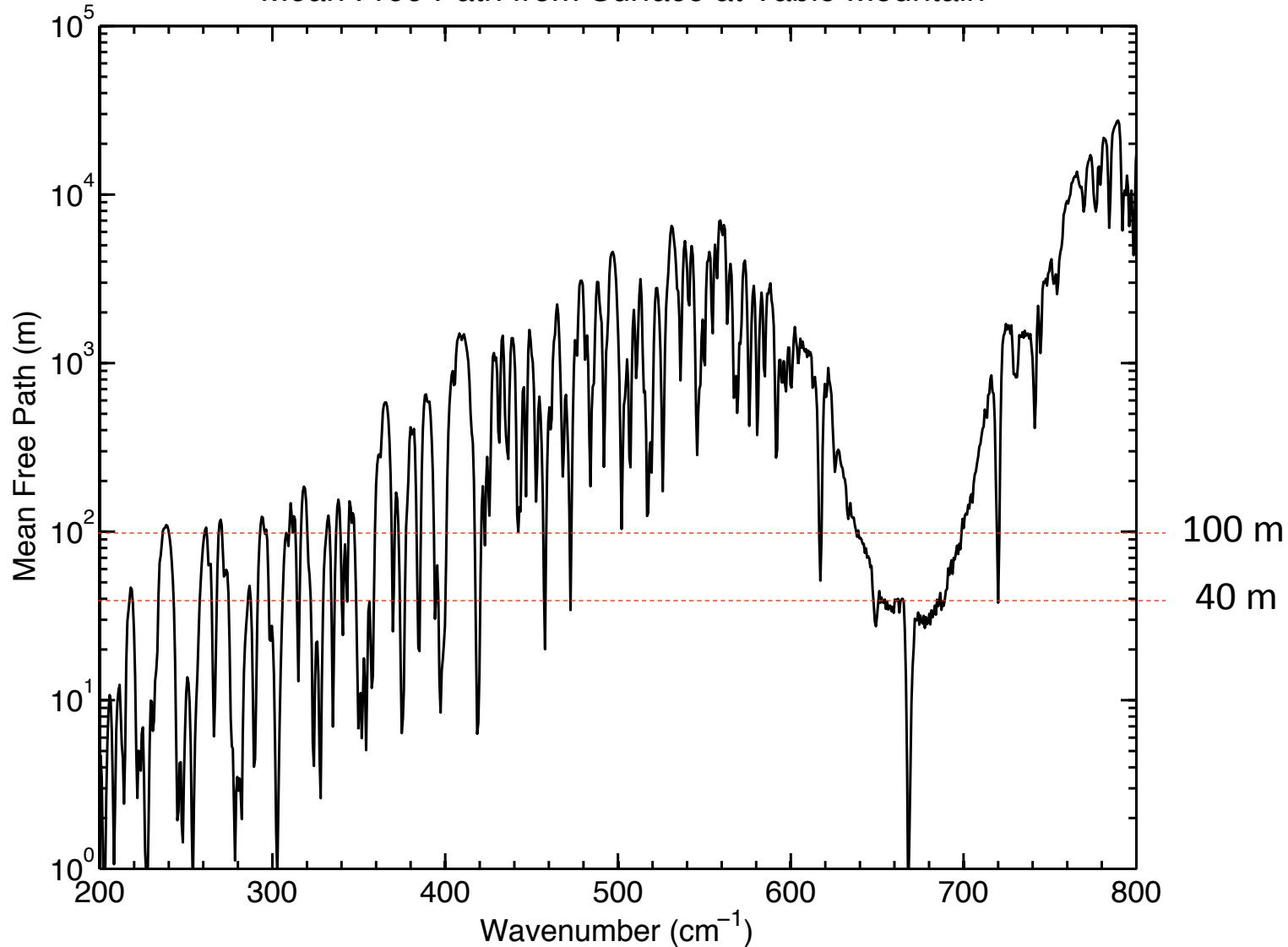
# FIRST Brightness Temperature Spectrum



Where in the atmosphere does the FIRST  
measured radiance originate?

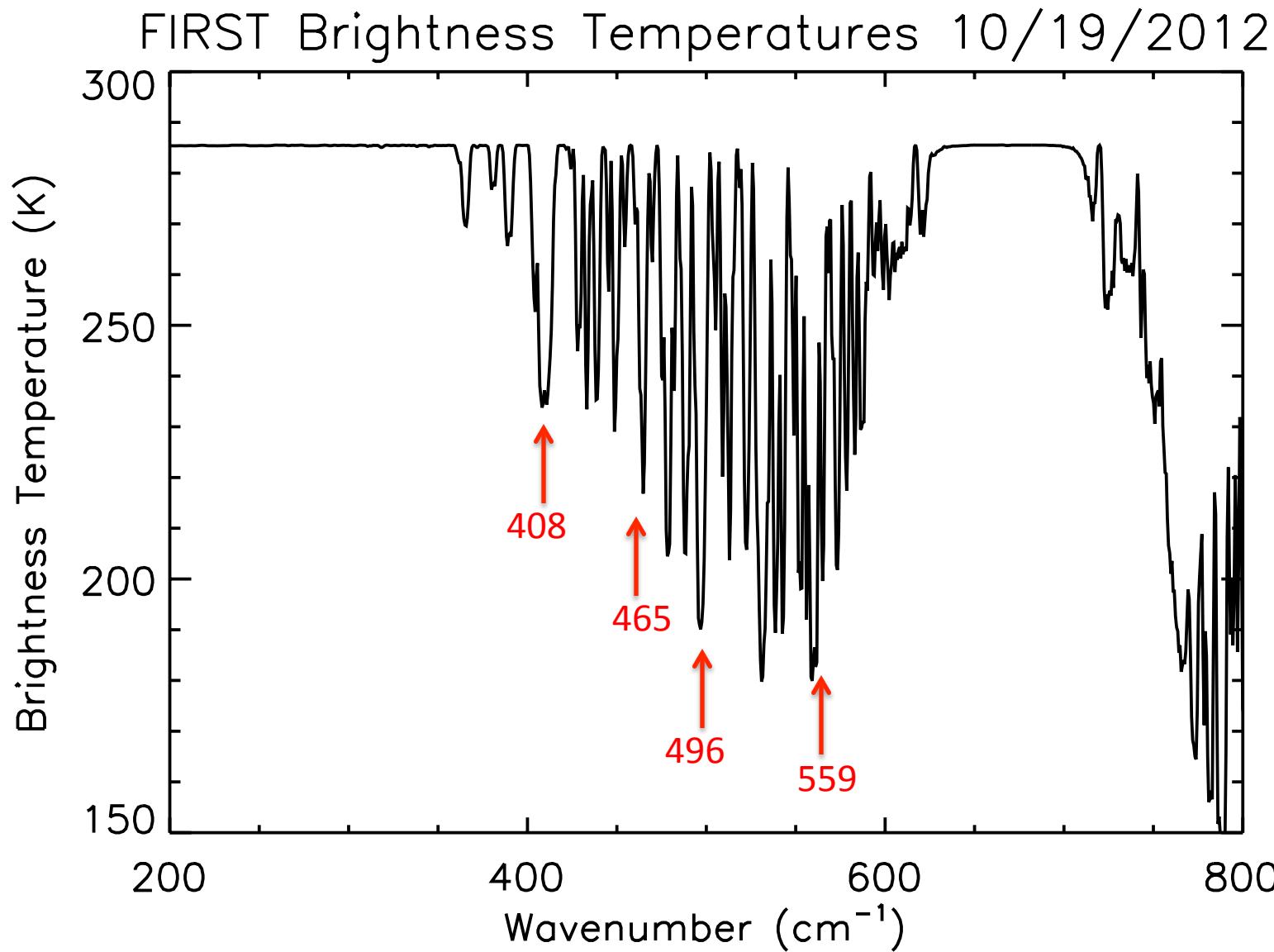
# Photon Mean Free Path (Distance to $\tau = 1$ )

Mean Free Path from Surface at Table Mountain

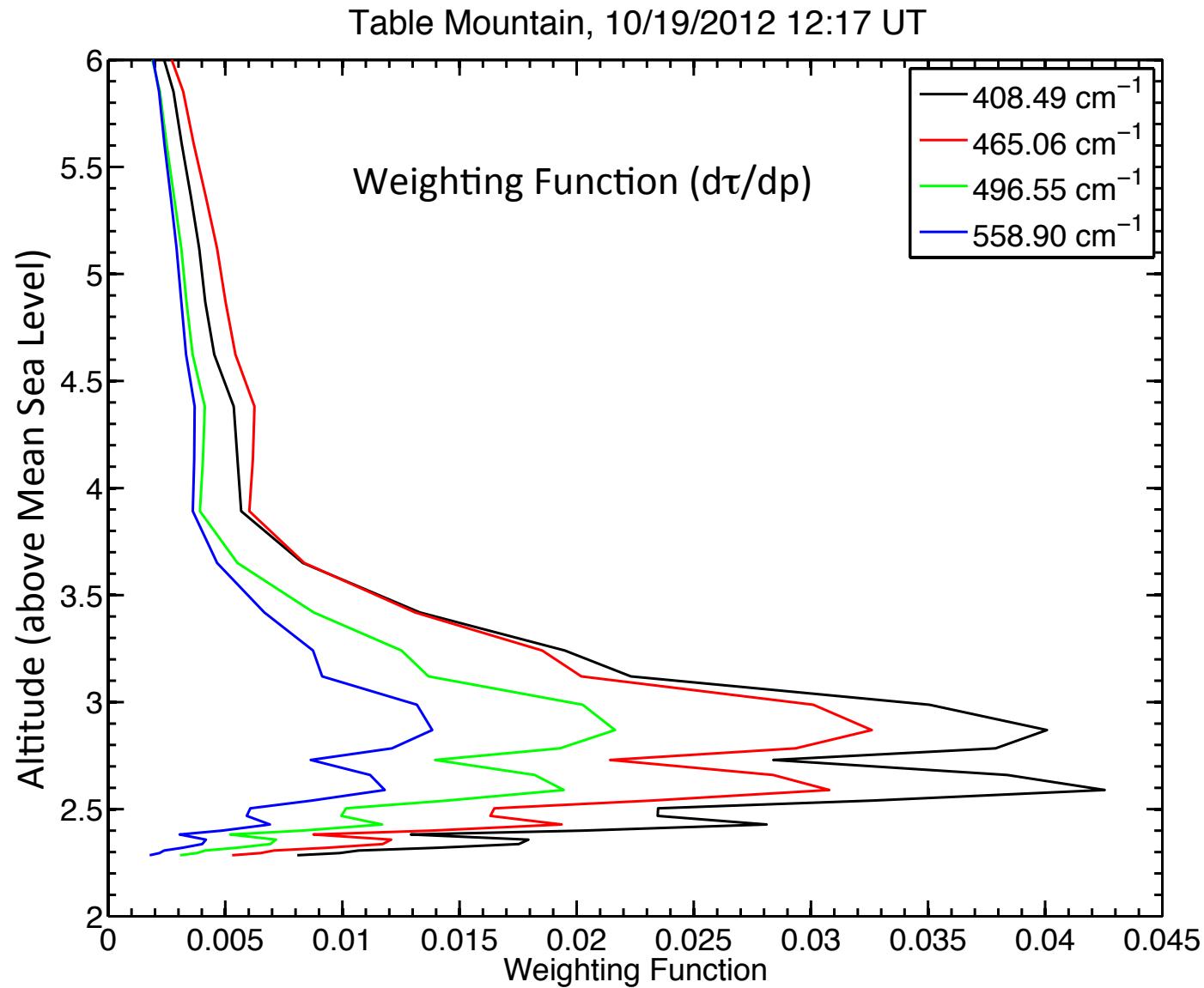


**Most of measured radiance originates within a few hundred meters above ground**

# FIRST Brightness Temperature Spectrum

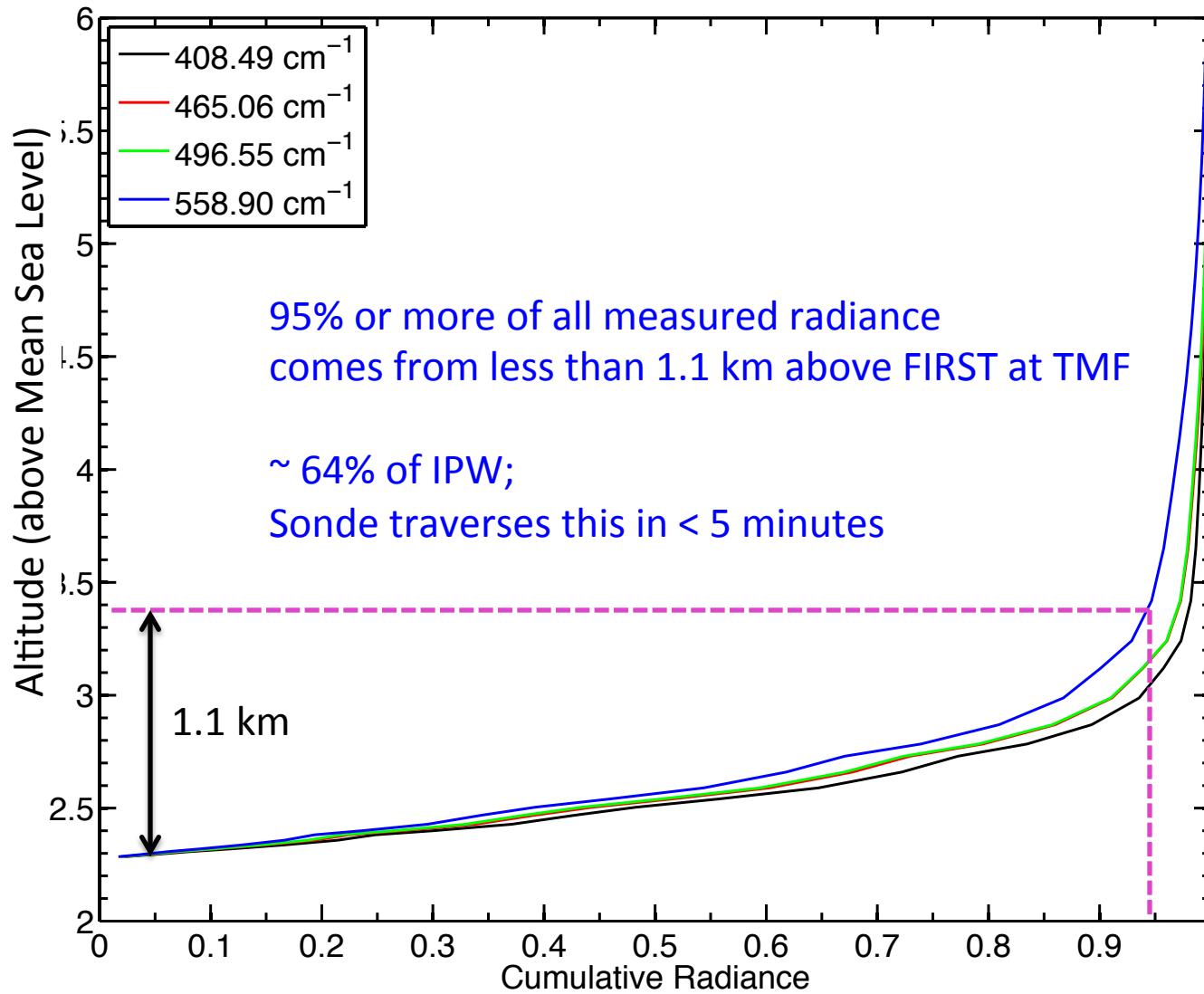


# Where does the FIRST measured radiance originate?



# Cumulative Radiance Distribution – Surface Upward

Table Mountain, 10/19/2012 12:17 UT

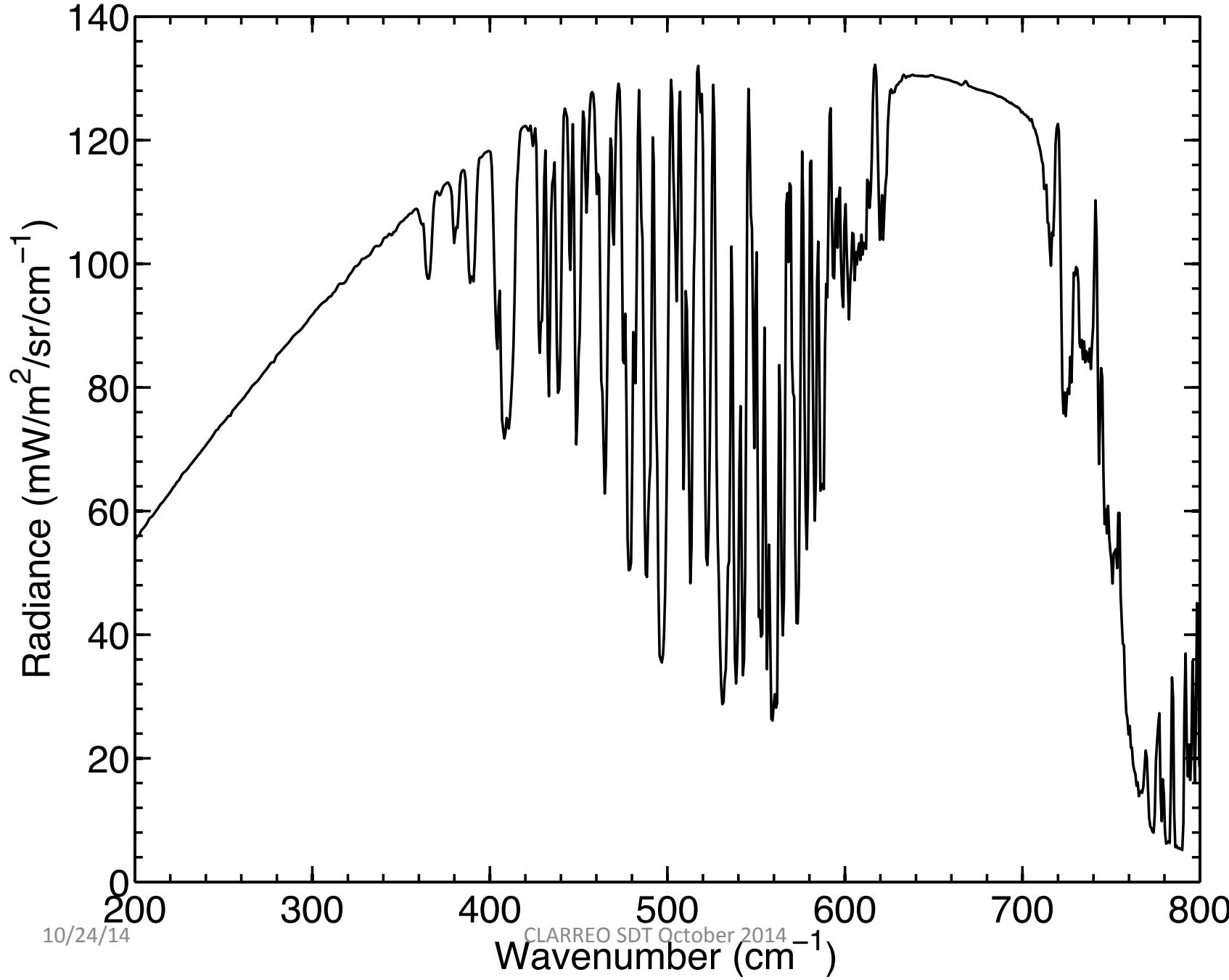


# Comparison of FIRST, LBLRTM, and assessment of measurement and model uncertainties

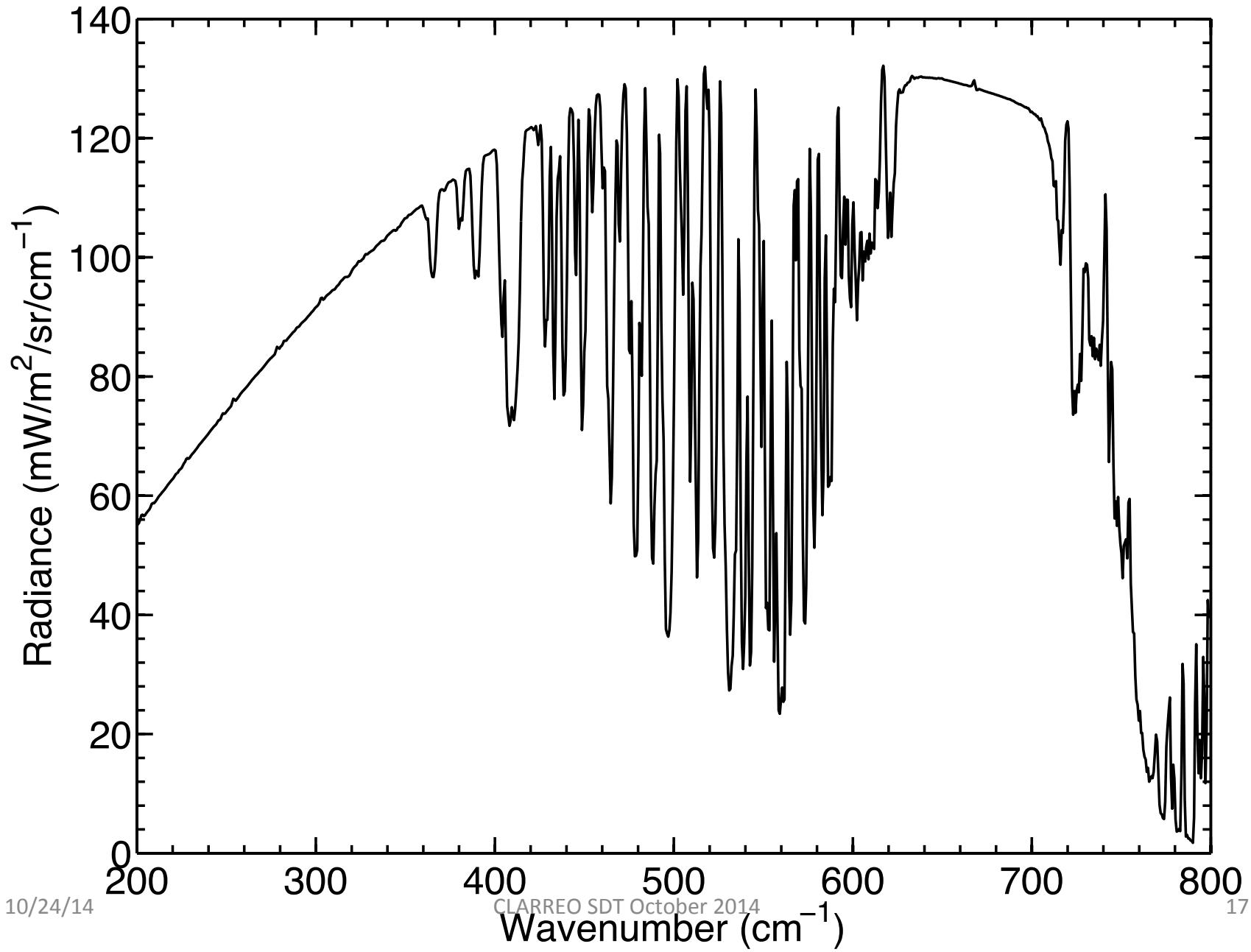
# Analysis Approach

- Compare FIRST measurements with LBLRTM calculations
  - Residual Radiance = LBLRTM minus FIRST
  - Account for 7 inch ‘hot path’ in instrument 5 K warmer than ambient
- Model uncertainties:
  - Radiosonde Temp (0.25 K) and H<sub>2</sub>O (5%)
  - Line strengths for H<sub>2</sub>O and CO<sub>2</sub>
  - Halfwidths
  - Model uncertainty is RSS of individual uncertainties
- Measurement uncertainties:
  - Absolute calibration
  - Detector variations (1- $\sigma$  of mean of six FIRST detectors)
  - Sky variability (over 30 minute average)
- Combined Uncertainty
  - RSS of Model and Measurement uncertainty
  - Compare Residual Radiance and Combined Uncertainty

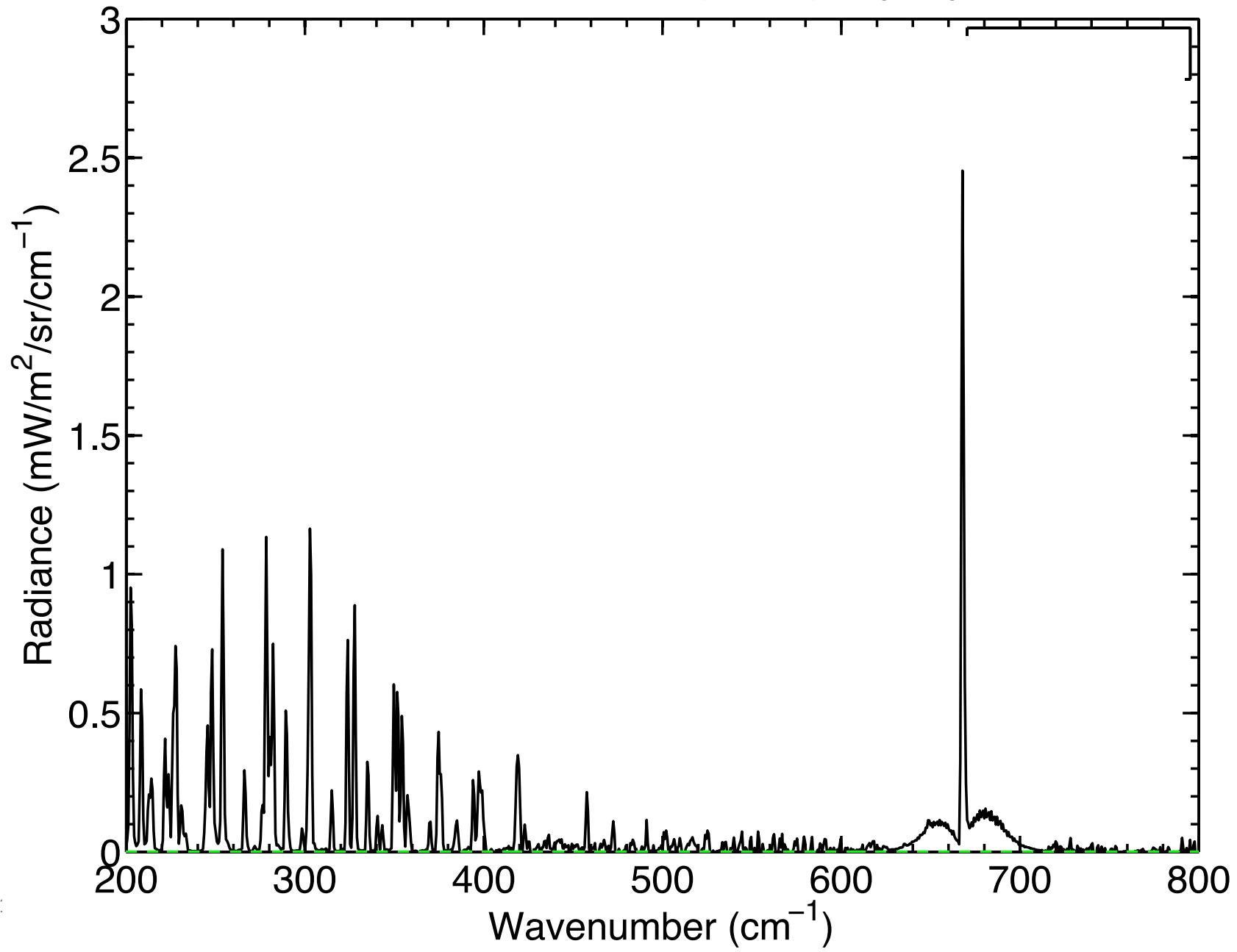
# FIRST Table Mountain Mean Radiances, 19–Oct–2012, 13:08:17 UT



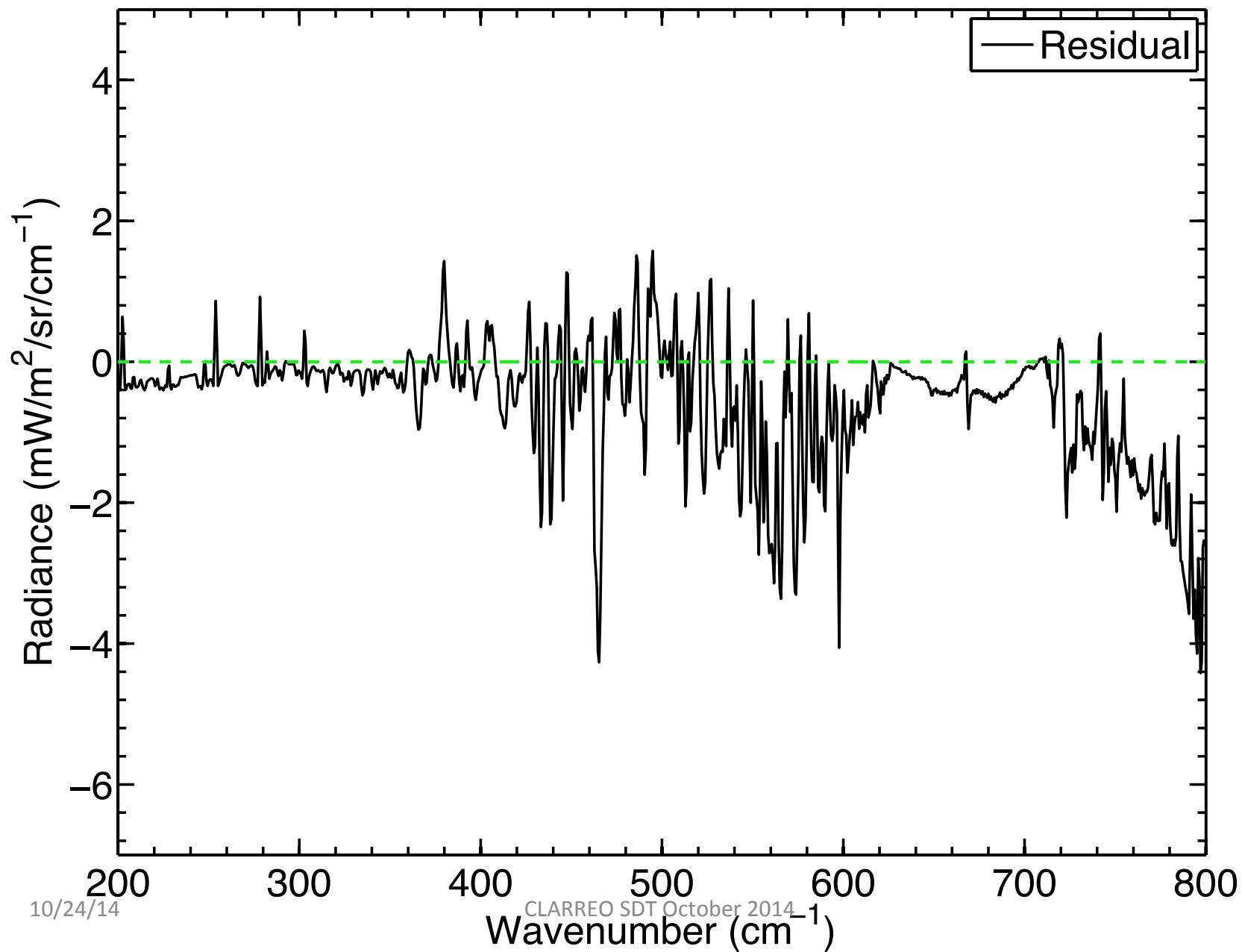
# Table Mountain Calculated Radiances, 12:17:25 UT Sonde 5K Hot Path



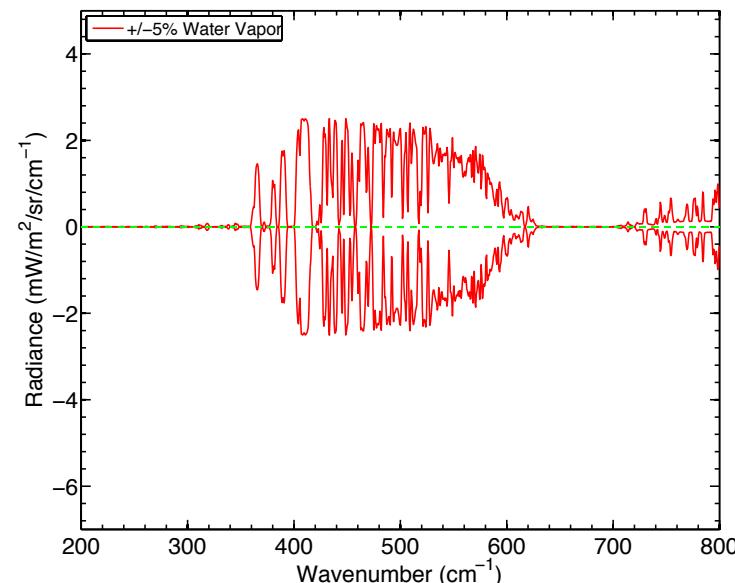
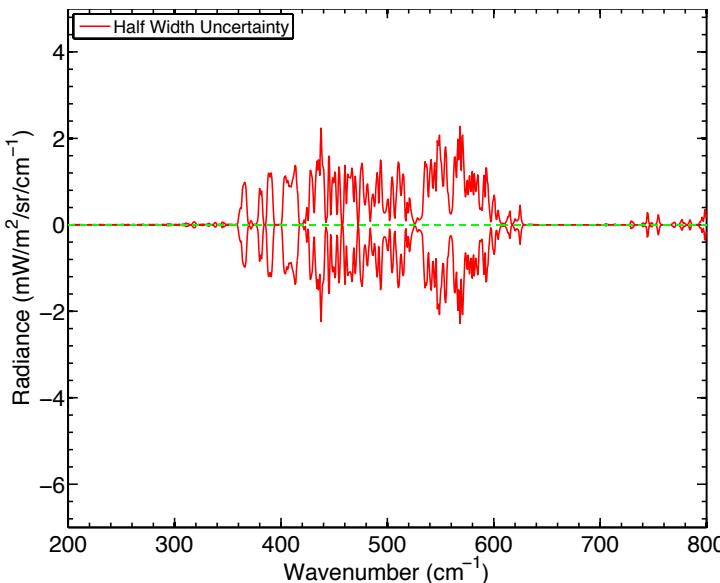
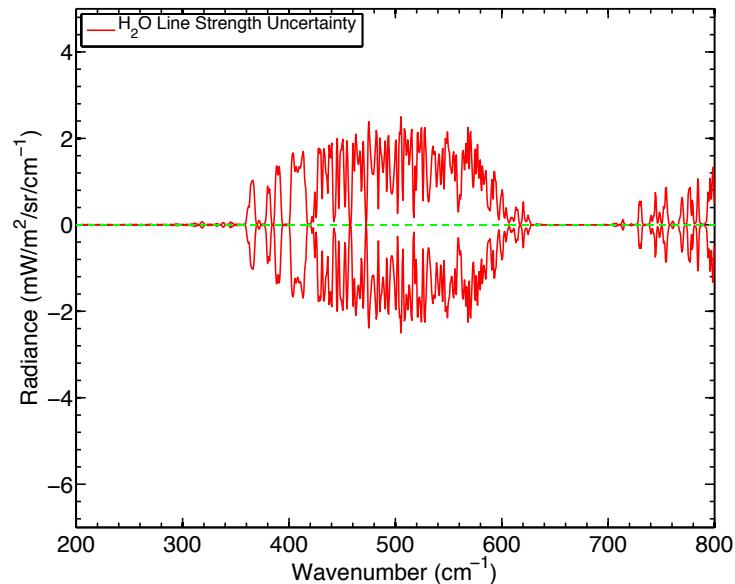
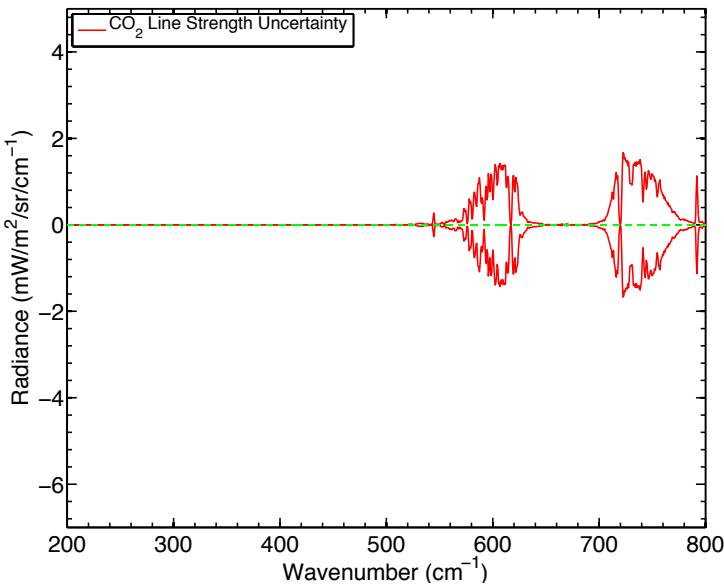
# Hot Path Radiance, TMF, 10/19/12



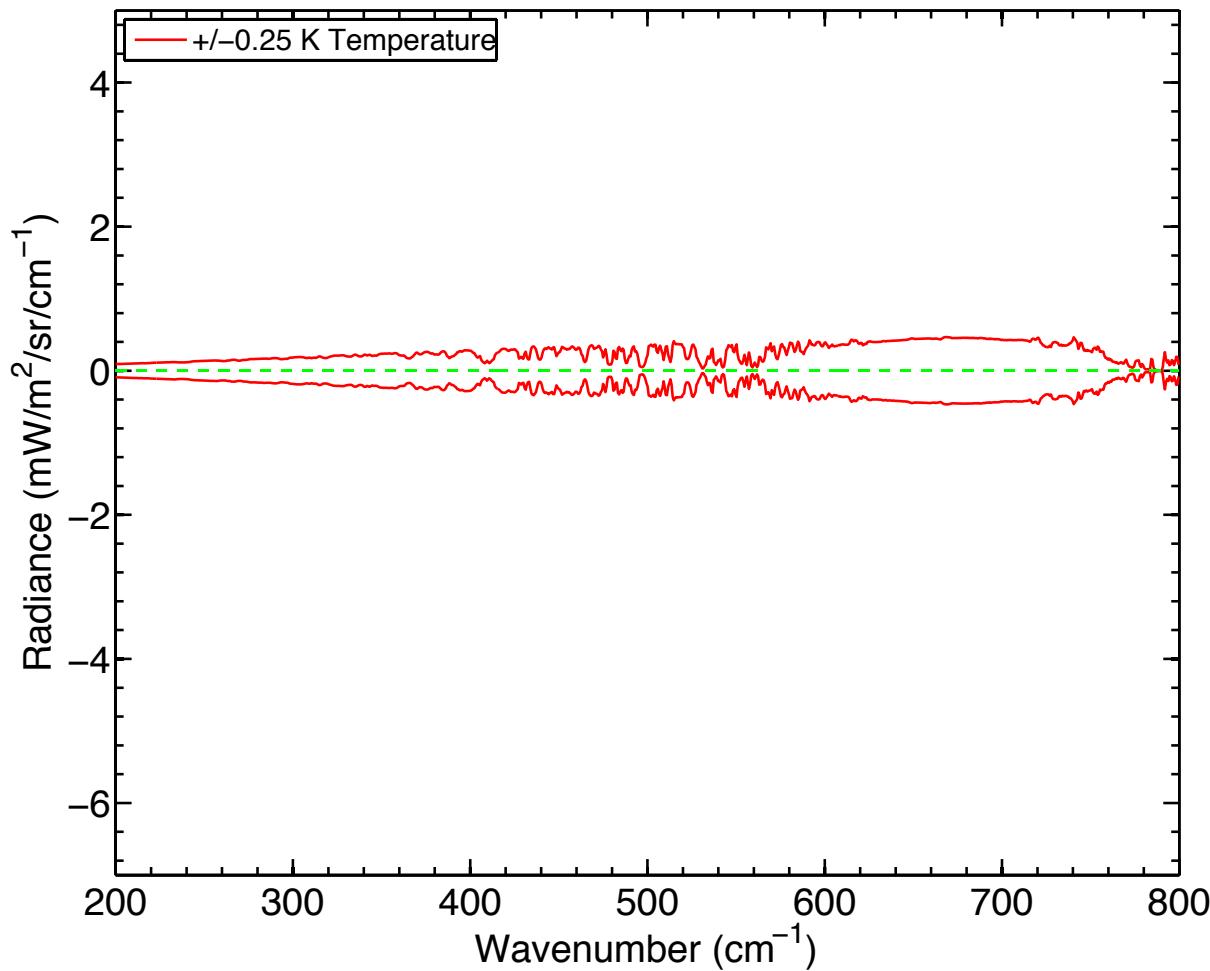
LBLRTM(10/19/2012, 12:17:25 UT) – FIRST(19–Oct–2012, 13:08:17 UT)  
5K Hot Path



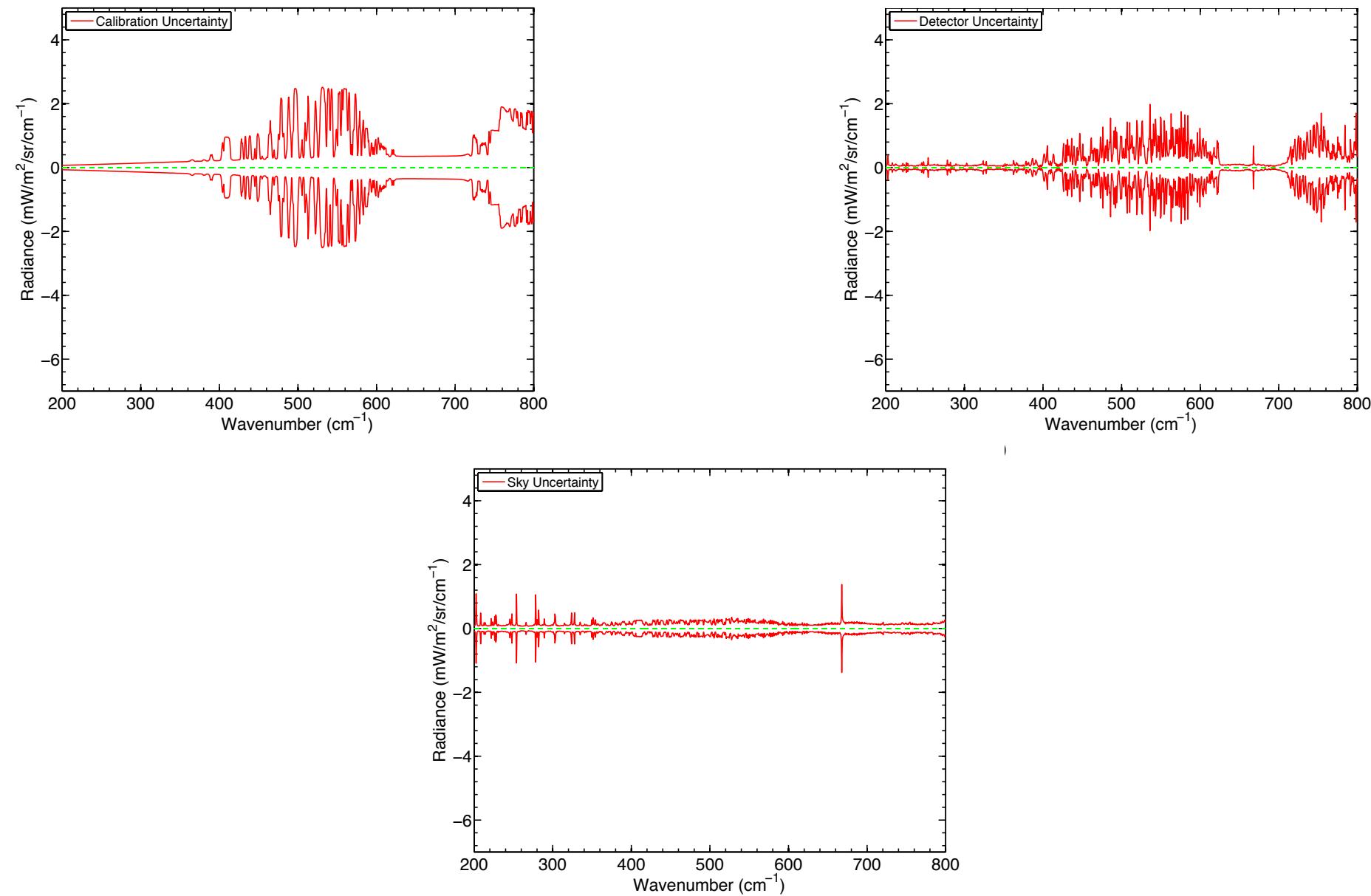
# Forward Model Uncertainties



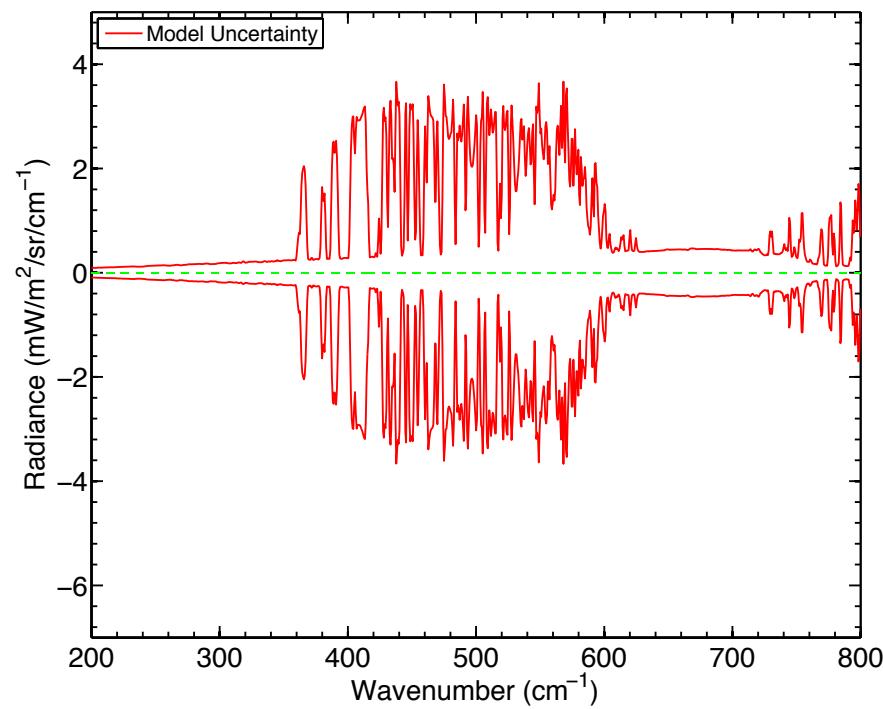
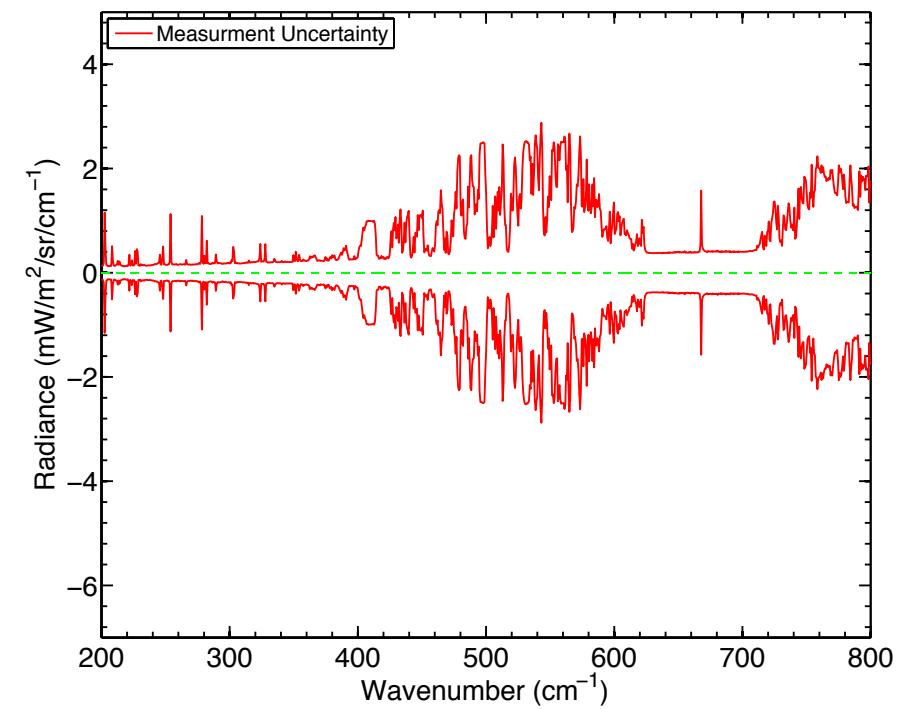
# Model Uncertainty due to Radiosonde Temperature



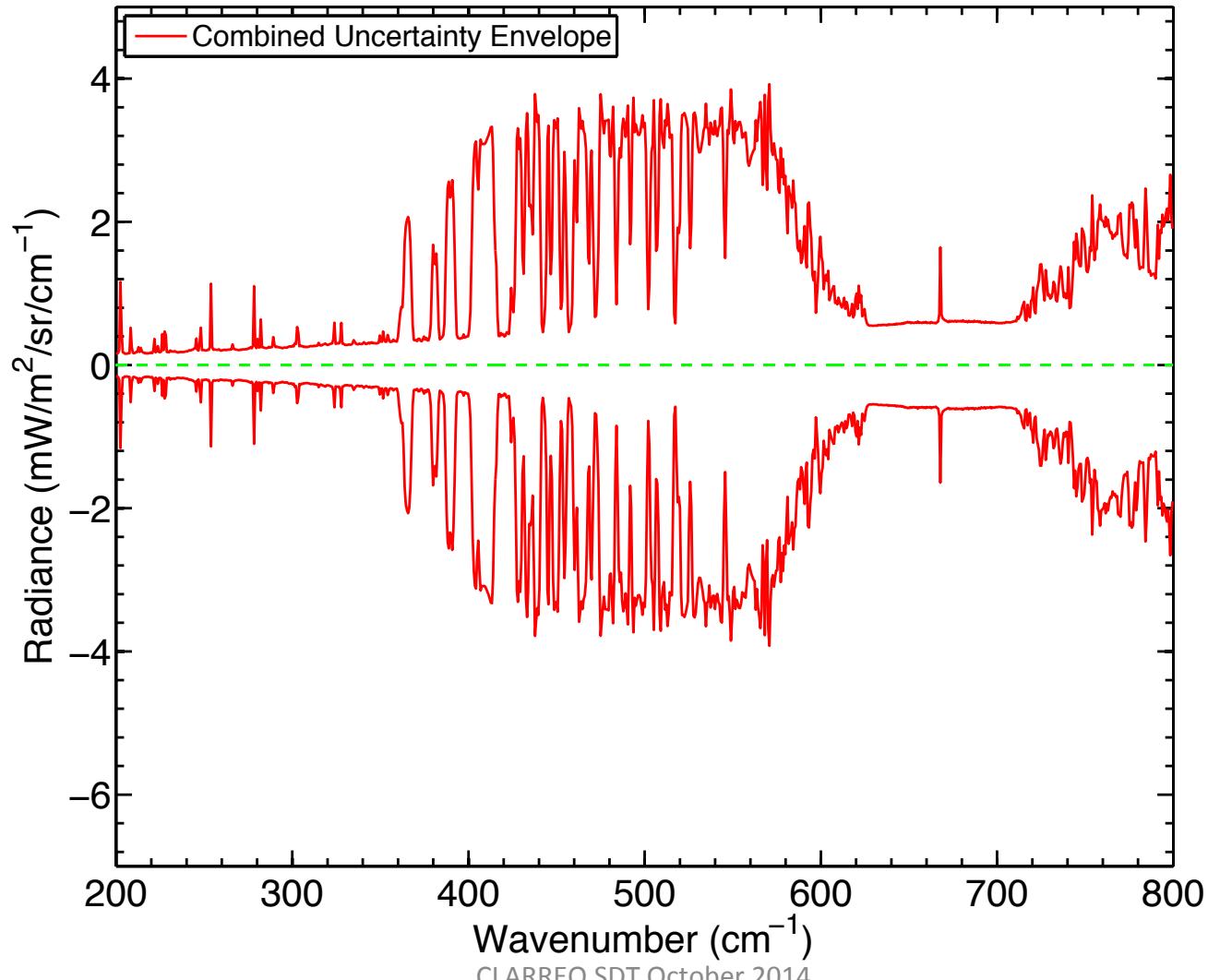
# Measurement Uncertainties



# Measurement Uncertainty and Model Uncertainty

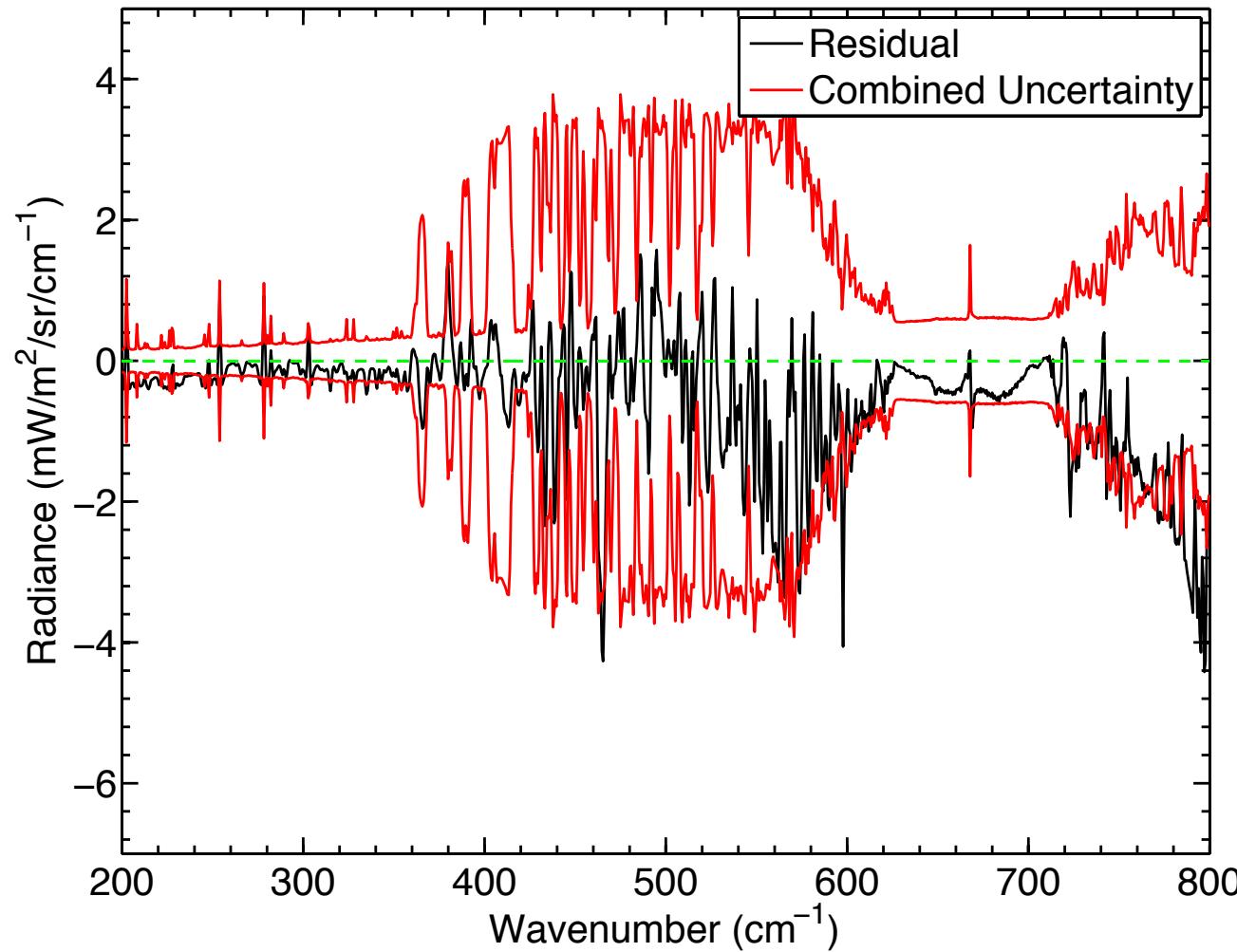


# Combined Uncertainty: RSS of Measurement and Model Uncertainty



# Comparison of Measurement/Model Residual and Combined Uncertainty

LBLRTM(10/19/2012, 12:17:25 UT) – FIRST(19–Oct–2012, 13:08:17 UT)  
5K Hot Path

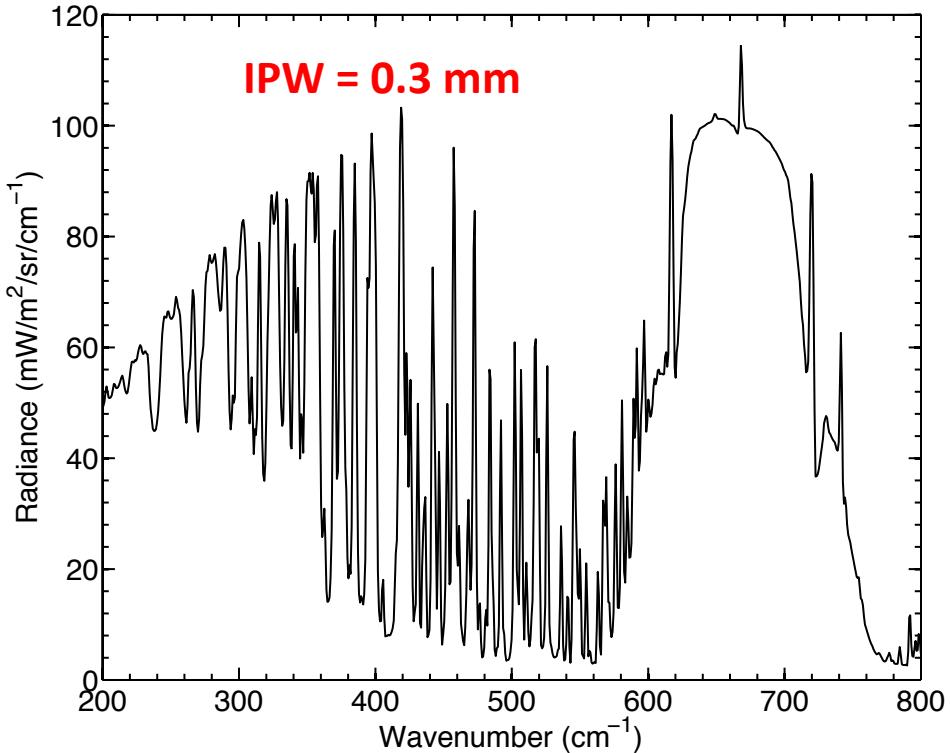


# First Look at results from Cerro Toco

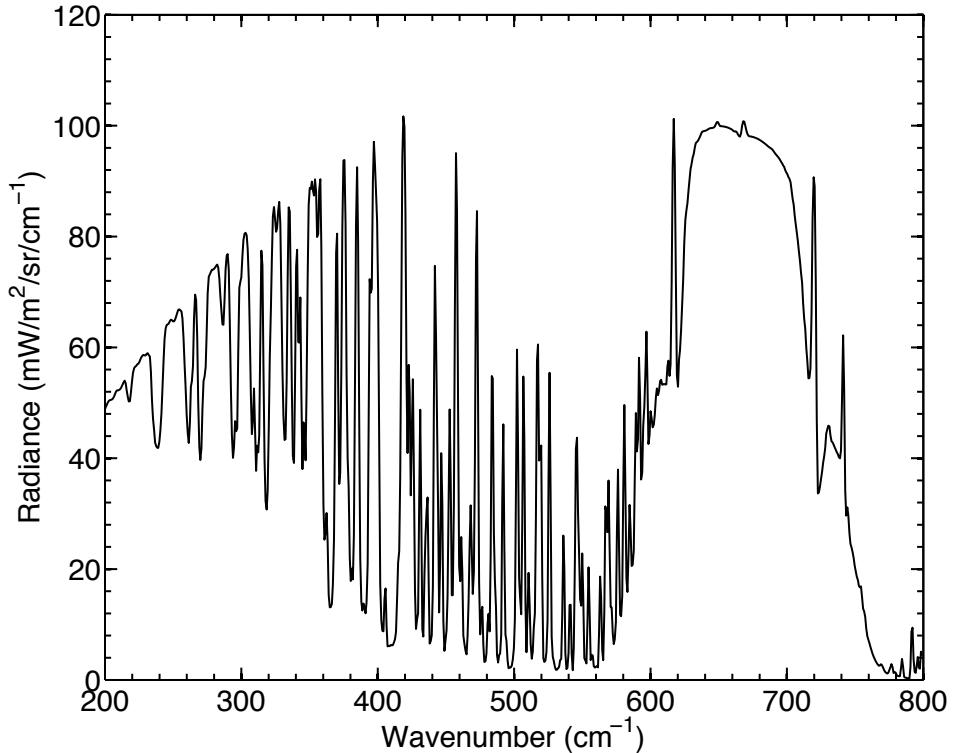
- FIRST data from Cerro Toco calibrated based on results in Latvakoski et al., 2013 (just as Table Mountain data)
- Received “final” radiosonde data from D. Turner/E. Mlawer in ~ July 2014
- Comparisons use LBLRTM and FIRST data
- Uncertainties (model, measurement) as per conditions at Cerro Toco
- Hot path (which is significant at Cerro Toco) not yet corrected

# FIRST and Model Radiances at Cerro Toco

FIRST Cerro Toco Mean Radiances, 24-Sep-2009 14:44:10 UT

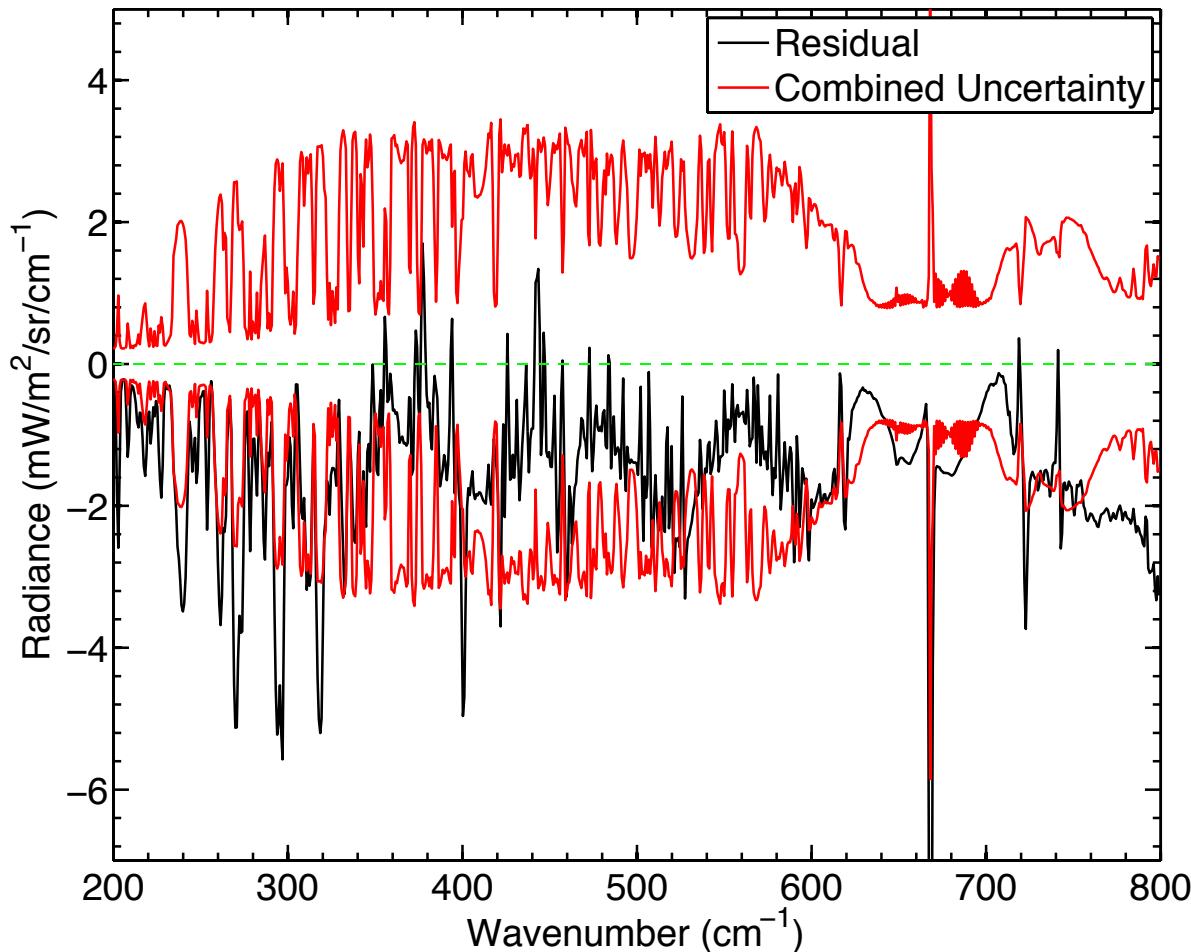


Cerro Toco Calculated Radiances, 14:41:42 UT Sonde



# Residual Radiance (LBLRTM – FIRST) and Uncertainty at Cerro-Toco

LBLRTM(09/24/2009, 14:41:42 UT) – FIRST(24-Sep-2009 14:44:10 UT)



**Measurement and Model Agree to Within Uncertainty at Cerro Toco**

## Summary

- FIRST has been calibrated to NIST standards across the far-IR and across relevant range of scene temperatures
- Results published in 2 papers in Applied Optics
- FIRST measurements at Table Mountain, Cerro Toco compared with LBLRTM calculations
- In-depth assessment of measurement, model uncertainties
- FIRST and LBLRTM agree in far-IR to within uncertainties of the measurement and the model
- Paper on Table Mountain data to be submitted to JQSRT
- Paper on Cerro Toco results to be submitted when analysis is complete

# Backup Slides

## FIRST Instrument Parameters

- 100 - 10 $\mu$ m (100 – 1000cm $^{-1}$ ) spectral range
- 0.643cm $^{-1}$  spectral resolution
- 7 cm aperture, f / 6.5
- 46°C and 17°C calibration blackbodies
- 10 LHe cooled Si bolometers
- 0.41° FOV each detector, in a sparsely populated 4.4° x 4.4° FOV focal plane
- Ge on Polypropylene beamsplitter
- Plane mirror Michelson FTS
- 11.5 sec. scan time
- 6 min. zenith sky integrations